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Renewable Energy in Industrial Applications

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Renewable Energy in Industrial Applications

By

Seshi Reddy Kasu

A research report submitted in partial fulfillment of the requirements for the degree of

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Research Advisor

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ABSTRACT

Manufacturing industry accounts for about one third of total energy use worldwide. Roughly three quarters of industrial energy use is related to the production of energy-intensive commodities such as ferrous and non-ferrous metals, chemicals and petrochemicals, non-metallic mineral materials, and pulp and paper. In these sectors, energy costs constitute a large proportion of total production costs, so managers pay particular attention to driving them down. As a result, the scope to improve energy efficiency tends to be less in these most energy intensive sectors than in those sectors where energy costs form a smaller proportion of total costs, such as the buildings and transportation sectors. A design of a small power generating system by using renewable energy sources, wind and solar by means of pumped-storage to replace the wind and/or solar power systems with a battery bank energy storage. This research evaluastes the energy efficiency of wind and solar pumped-storage power generation system, and it demonstrates that it is well suited for remote residential applications with intermittent wind and/or solar energy. Through design and cost analysis, it is shown how this type of power systems, could be a very good alternative, with economic benefits and positive social effect. The advantage of pumped storage power system is evaluated, for conditions of intermittent wind, showing a significant improvement of power regulation, resulting in a power-on-demand system capability, concomitant to extra economic benefits. It also evaluates how a solar car can be used especially in a remote areas where gas and natural resources are not available.

Thesis Supervisor: Dr. Florian Misoc
Title: Professor of Electrical and Computer
Engineering Technology

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Introduction

This thesis is aiming at the design of a small power generating system by using renewable energy sources, wind and solar by means of pumped-storage to replace the wind and/or solar power systems with a battery bank energy storage. This research evaluates the energy efficiency of wind and solar pumped-storage power generation system, and it demonstrates that it is well suited for remote residential applications with intermittent wind and/or solar energy. Through design and cost analysis, it is shown how this type of power systems, could be a very good alternative, with economic benefits and positive social effect. The advantage of pumped storage power system is evaluated, for conditions of intermittent wind, showing a significant improvement of power regulation, resulting in a power-on-demand system capability, concomitant to extra economic benefits. It also evaluates the transportation by solar car especially in remote residential areas where gas/ fuel is not available.

Background

Providing electricity and transportation to remote residential location is costly and technically challenging; from the point of view of system design, system construction and operation and maintenance. Current renewable energy systems relay on banks of batteries for energy storage, which proves to be costly, require periodic maintenance/monitoring, and be to some extent dangerous (because of the acidic electrolyte, and the flammable/explosive Hydrogen-rich gasses it can leak into the storage building).

Design proposed in base papers for power stations

The design consists of wind-solar and pumped-storage hybrid power supply system along with PV generation, wind power generation, pumping and hydropower and other subsystems. The design works according to the solar energy distribution characteristics of site area. L. R. Li, B. Wu, X. Li, F. Zhou, Y. Li (L. R. Li, 2010) used solar plates and wind turbine to gather energy from sun's radiation and the wind. The energy is converted into electrical energy by means of converters and is used to drive the motor that pumps water to a reservoir placed at a certain height. Hydro Power unit is also used in order to increase the power generation capability that should meet the conditions to sync with the main power grid. The design is efficient for large amount of power generation.

The other design proposed by "Nichita, Livinti, and Enache" ("Nichita, 2014) research team is similar to the design proposed by L. R. Li, B. Wu, X. Li, F. Zhou, Y. Li (L. R. Li, 2010) with slight modifications reducing the size to an extent by using less number of components.

Disadvantages/Problems

- This model cannot be used for residential applications due its large size, more cost and less efficient compared to the model proposed in this paper.
- The energy from the natural resources is not stable so there will be some ups and downs in the power which results to breakdown when it is connected to grid.

Renewable Energy Sources

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.

Wind power is growing at the rate of 30% annually, with a worldwide installed capacity of 282,482 megawatts (MW) at the end of 2014, and is widely used in Europe, Asia, and the United States. At the end of 2012 the photovoltaic (PV) capacity worldwide was 100,000 MW, and PV power stations are popular in Germany and Italy. Solar thermal power stations operate in the USA and Spain, and the largest of these is the 354 MW SEGS power plant in the Mojave Desert. The world's largest geothermal power installation is The Geysers in California, with a rated capacity of 750 MW. Brazil has one of the largest renewable energy programs in the world, involving production of ethanol fuel from sugar cane, and ethanol now provides 18% of the country's automotive fuel. Ethanol fuel is also widely available in the USA.

Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services. Renewable energy provides 31.4% of electricity generation worldwide as of 2013. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas: for example, 14% in the U.S. state of Iowa, 40% in the northern German state of Schleswig-Holstein, and 49% in Denmark. Some countries get most of their power from renewables, including Iceland (100%), Norway (98%), Brazil (86%), Austria (62%), New Zealand (65%), and Sweden (54%) (Renewable Energy , 2013).

Working of Renewable Energy Sources

In this research I had designed my power station based on three types of renewable energy sources, let us see the working of all the three types.

Solar Panels

Solar (or photovoltaic) cells (Physics, n.d.) convert the sun's energy into electricity. Whether they're adorning your calculator or orbiting our planet on satellites, they rely on the photoelectric effect: the ability of matter to emit electrons when a light is shone on it. Silicon is what is known as a semi-conductor,

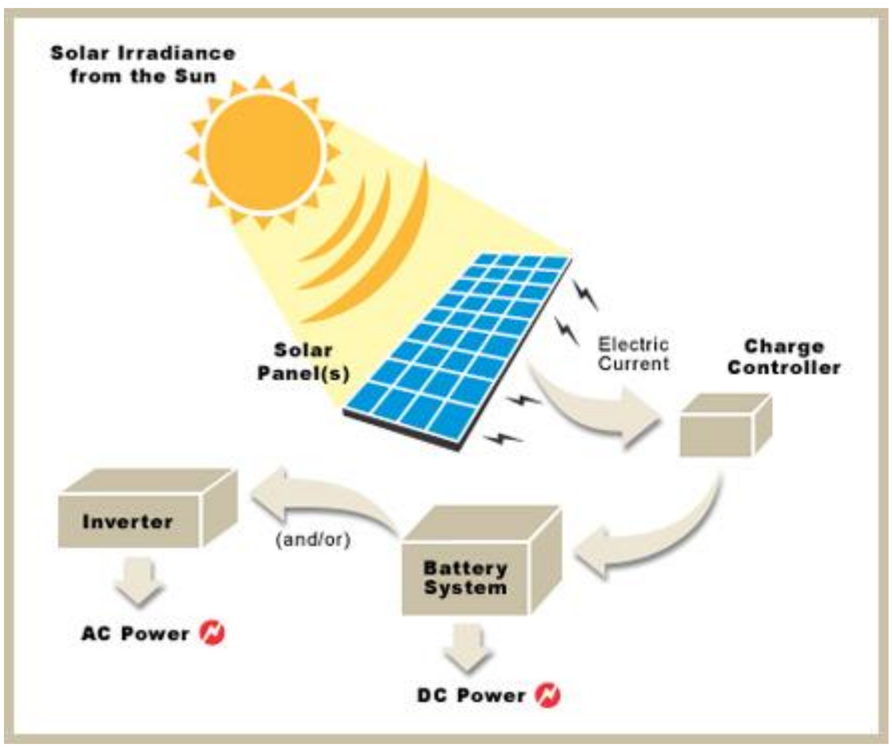

Figure 1: Working of solar panel, Reprinted from (Chola Power, n.d.)

Meaning that it shares some of the properties of metals and some of those of an electrical insulator, making it a key ingredient in solar cells. Let's take a closer look at what happens when the sun shines onto a solar cell. Sunlight is composed of miniscule particles called photons, which radiate from the sun. As these hit the silicon atoms of the solar cell, they transfer their energy to loose electrons, knocking them clean off the atoms. The photons could be compared to the white ball in a game of pool, which passes on its energy to the coloured balls it strikes. Freeing up electrons is however only half the work of a solar cell: it then needs to herd these stray electrons into an electric current. This involves creating an electrical imbalance within the cell, which acts a bit like a slope down which the electrons will flow in the same direction. Creating this imbalance is made possible by the internal organization of silicon. Silicon atoms are arranged together in a tightly bound structure. By squeezing small quantities of other elements into this structure, two different types of silicon are created: n-type, which has spare electrons, and p-type, which is missing electrons, leaving 'holes' in their place. When these two materials are placed side by side inside a solar cell, the n-type silicon's spare electrons jump over to fill the gaps in the p-type silicon. This means that the n-type silicon becomes positively charged, and the p-type silicon is negatively charged, creating an electric field across the cell. Because silicon is a semi-conductor, it can act like an insulator, maintaining this imbalance. As the photons smash the electrons off the silicon atoms, this field drives them along in an orderly manner, providing the electric current to power calculators, satellites and everything in between.

Advantages

- Solar power (shahan, 2013) helps to slow/stop global warming. Global warming threatens the survival of human society, as well as the survival of countless species. Luckily, decades (or even centuries) of research have led to efficient solar panel systems that create electricity without producing global warming pollution. Solar power is now very clearly one of the most important solutions to the global warming crisis.

- Solar power saves society billions or trillions of dollars. Even long before society's very existence is threatened by global warming, within the coming decades, global warming is projected to cost society trillions of dollars if left unabated. So, even ignoring the very long-term threat of societal suicide, fighting global warming with solar power will likely save society billions or even trillions of dollars.

- Solar power saves you money. Putting solar PV panels on your roof is likely to save you tens of thousands of dollars. The average 20-year savings for Americans who went solar in 2011 were projected to be a little over $20,000. In the populous states of New York, California, and Florida, the projected savings were over $30,000. In the sunny but expensive paradise known as Hawaii, the projected savings were nearly $65,000!

- Beyond solar PV panels, it's worth noting that solar energy can actually save you money in about a dozen other ways as well — with proper planning and household design choices.

- Solar power provides energy reliability. The rising and setting of the sun is extremely consistent. All across the world, we know exactly when it will rise and set every day of the year. While clouds may be a bit less predictable, we do also have fairly good seasonal and daily projections for the amount of sunlight that will be received in different locations. All in all, this makes solar power an extremely reliable source of energy.

- Solar power provides energy security. On top of the above reliability benefit, no one can go and buy the sun or turn sunlight into a monopoly. Combined with the simplicity of solar panels, this also provides the notable solar power advantage of energy security, something the US military has pointed out for years, and a major reason why it is also putting a lot of its money into the development and installation of solar power systems.

- Solar power provides energy independence. Similar to the energy security boost, solar power provides the great benefit of energy independence. Again, the "fuel" for solar panels cannot be bought or monopolized. It is free for all to use. Once you have solar panels on your roof, you have an essentially independent source of electricity that is all yours. This is important for individuals, but also for cities, counties, states, countries, and even companies. I was recently in Ukraine touring various cleantech initiatives and projects. While there, I discovered that Ukraine in recent years has saved approximately $3 billion in reduced oil and gas imports from Russia thanks to the solar power plants developed by a single developer. Impressive.

- Solar power creates jobs. As a source of energy, solar power is a job-creating powerhouse. Money invested in solar power creates two to three times more jobs than money invested in coal or natural gas. Here's a simple chart on that point:

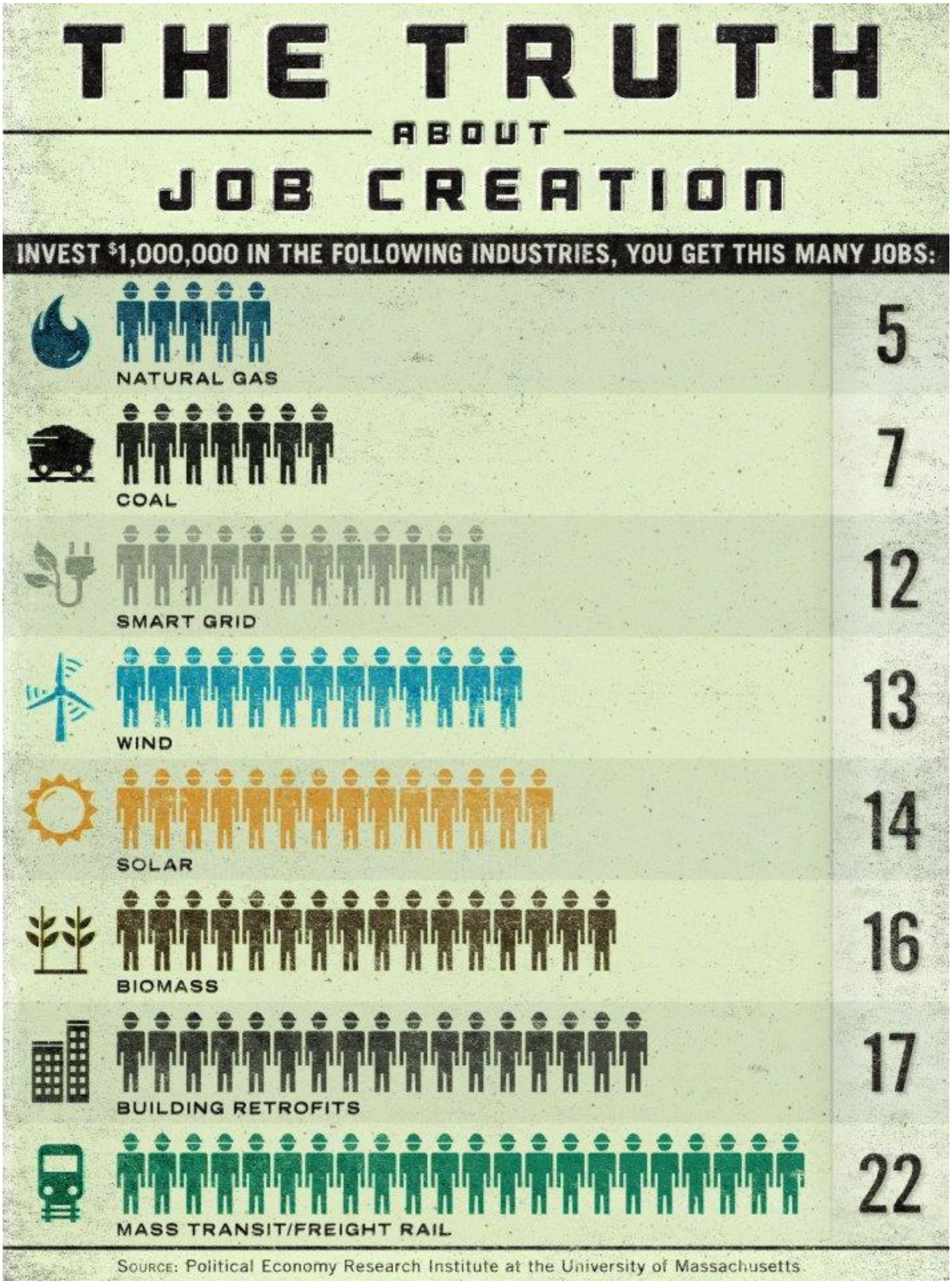

Figure 2: Job Creations due to Solar, Reprinted from (shahan, 2013)

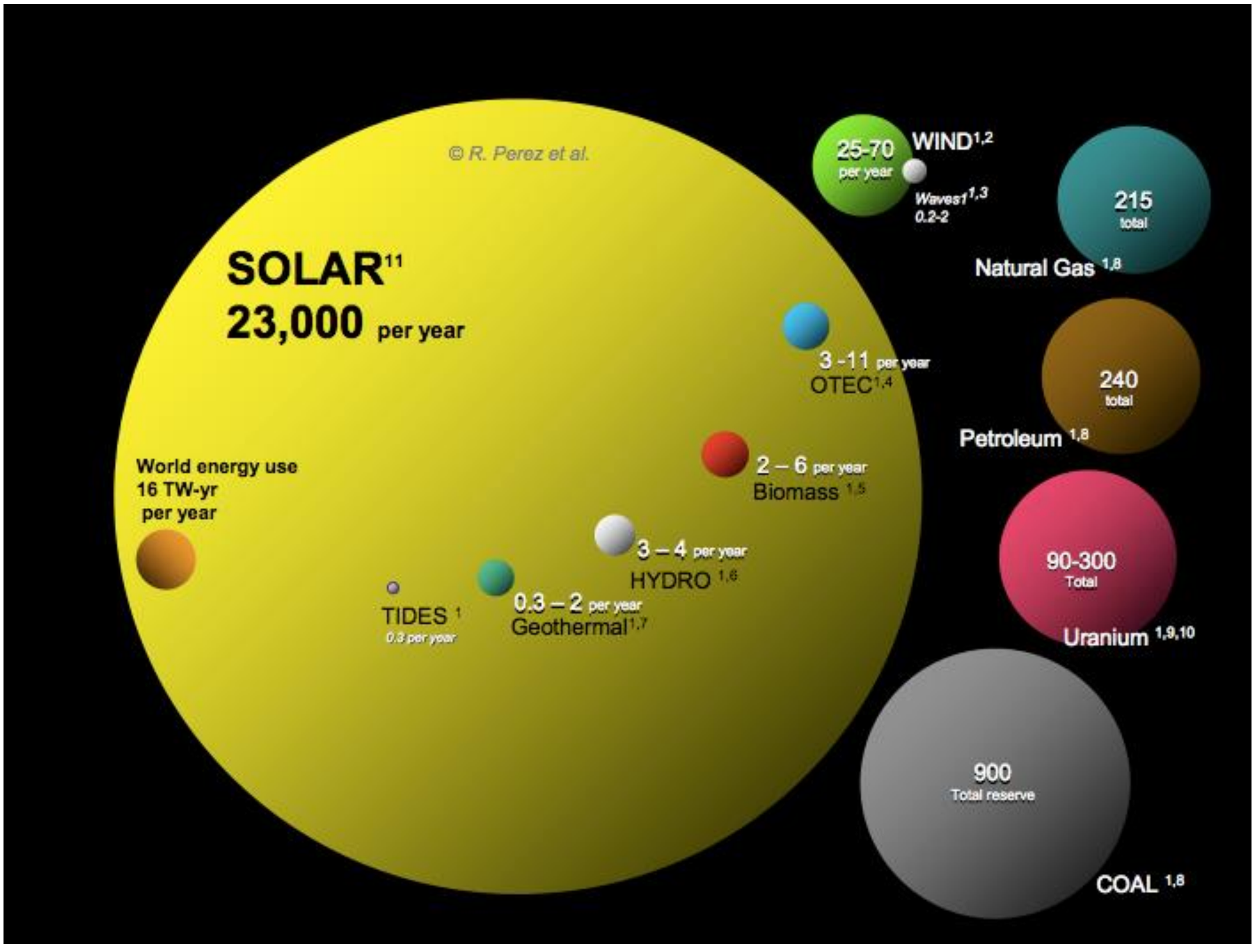

Figure 3: Annual Energy potential of Renewable energy resources vs total known recoverable reserves of non-renewable energy sources, Reprinted from (shahan, 2013)

Disadvantages

Solar power (shahan, 2013) disadvantages are actually not so plentiful. In fact, there's only one notable disadvantage to solar power that I can think of. That disadvantage is that the sun doesn't shine 24 hours a day. When the sun goes down or is heavily shaded, solar PV panels stop producing electricity. If we need electricity at that time, we have to get it from some other source. In other words, we couldn't be 100% powered by solar panels. At the very least, we need batteries to store electricity produced by solar panels for use sometime later.

Working of Wind Turbines

Wind turbines (Energy, n.d.) operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. So how do wind turbines make electricity? Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. View the wind turbine animation to see how a wind turbine works or take a look inside.

Wind is a form of solar energy and is a result of the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and the rotation of the earth. Wind flow patterns and speeds vary greatly across the United States and are modified by bodies of water, vegetation, and differences in terrain. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity.

The terms wind energy or wind power describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

Types of Wind Turbines

Modern wind turbines fall into two basic groups: the horizontal-axis variety, as shown in the photo to the far right, and the vertical-axis design, like the eggbeater-style. Darrieus model pictured to the immediate right, named after its French inventor. Horizontal-axis wind turbines typically either have two or three blades. These three-bladed wind turbines are operated "upwind," with the blades facing into the wind.

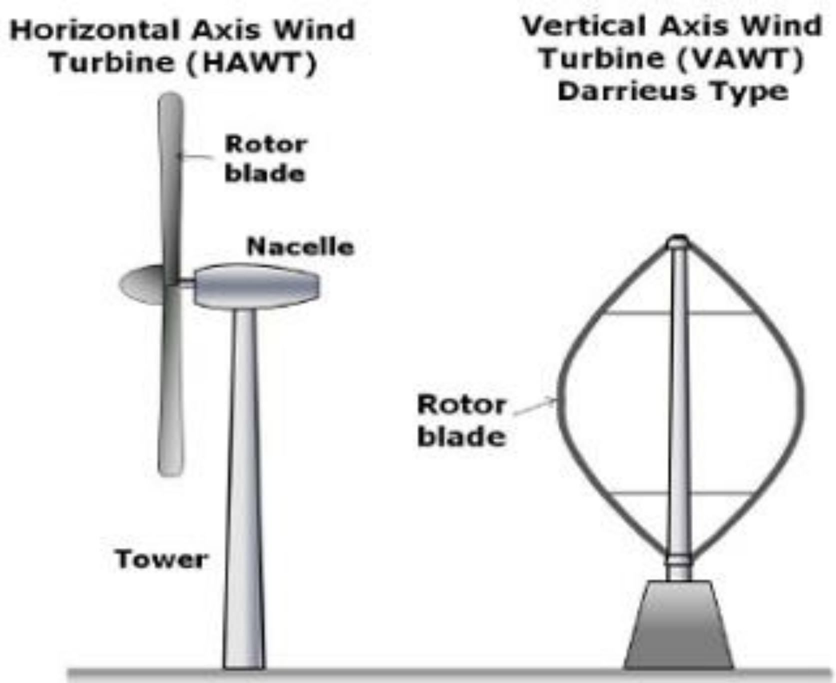

Figure 4: Types of Wind turbine, Reprinted from (Boston University, n.d.)

Wind turbines can be built on land or offshore in large bodies of water like oceans and lakes. Though the United States does not currently have any offshore wind turbines, the Department of Energy is funding efforts that will make this technology available in U.S. waters.

Sizes of Wind Turbines

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts. Larger wind turbines are more cost effective and are grouped together into wind farms, which provide bulk power to the electrical grid. In recent years, there has been an increase in large offshore wind installations in order to harness the huge potential that wind energy offers off the coasts of the U.S.

Single small turbines, below 100 kilowatts, are used for homes, telecommunications dishes, or water pumping. Small turbines are sometimes used in connection with diesel generators, batteries, and photovoltaic systems. These systems are called hybrid wind systems and are typically used in remote, off-grid locations, where a connection to the utility grid is not available.

Learn more about what the Wind Program is doing to support the deployment of small and mid-sized turbines for homes, businesses, farms, and community wind projects.

Advantages

1. The wind (Ryan. V, 2015) is free and with modern technology it can be captured efficiently.
2. Once the wind turbine is built the energy it produces does not cause greenhouse gases or other pollutants.
3. Although wind turbines can be very tall each takes up only a small plot of land. This means that the land below can still be used. This is especially the case in agricultural areas as farming can still continue.
4. Many people find wind farms an interesting feature of the landscape.
5. Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.
6. Wind turbines have a role to play in both the developed and third world.
7. Wind turbines are available in a range of sizes which means a vast range of people and businesses can use them. Single households to small towns and villages can make good use of range of wind turbines available today.

Disadvantages

1. The strength of the wind is not constant and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all.
2. Many people feel that the countryside should be left untouched, without these large structures being built. The landscape should left in its natural form for everyone to enjoy.
3. Wind turbines are noisy. Each one can generate the same level of noise as a family car travelling at 70 mph.
4. Many people see large wind turbines as unsightly structures and not pleasant or interesting to look at. They disfigure the countryside and are generally ugly.
5. When wind turbines are being manufactured some pollution is produced. Therefore wind power does produce some pollution.
6. Large wind farms are needed to provide entire communities with enough electricity. For example, the largest single turbine available today can only provide enough electricity for 475 homes, when running at full capacity. How many would be needed for a town of 100 000 people?

Hydro Energy

So just how do we get electricity from water? Actually, hydroelectric (USGS, 2015) and coal-fired power plants produce electricity in a similar way. In both cases a power source is used to turn a propeller-like piece called a turbine, which then turns a metal shaft in an electric generator, which is the motor that produces electricity. A coal-fired power plant uses steam to turn the turbine blades; whereas a hydroelectric plant uses falling water to turn the turbine. The results are the same. Take a look at this diagram.

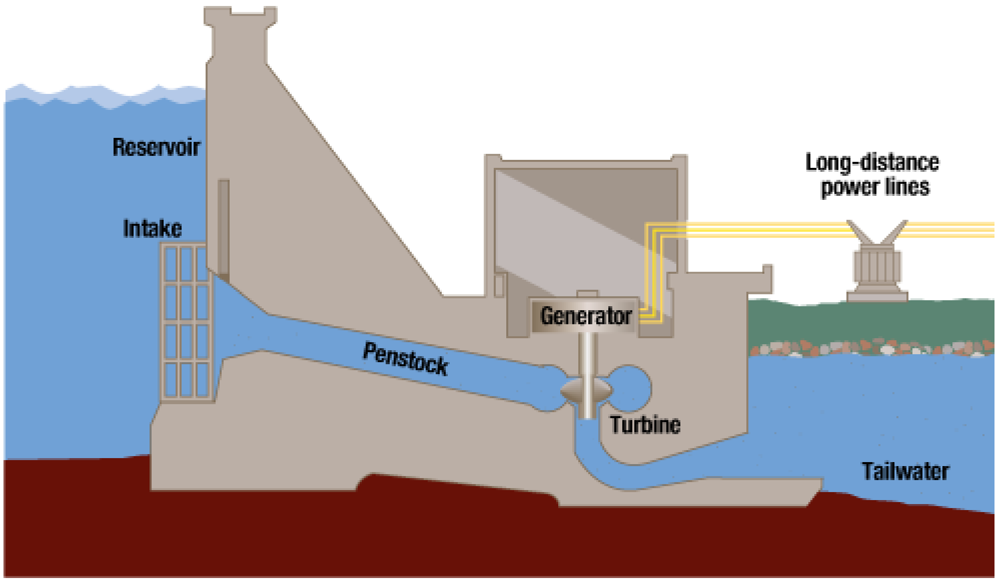

Figure 5: Working of Hydro Energy Reprinted from (Tennesse valley Authority, 2015)

The theory is to build a dam on a large river that has a large drop in elevation (there are not many hydroelectric plants in Kansas or Florida). The dam stores lots of water behind it in the reservoir. Near the bottom of the dam wall there is the water intake. Gravity causes it to fall through the penstock inside the dam. At the end of the penstock there is a turbine propeller, which is turned by the moving water. The shaft from the turbine goes up into the generator, which produces the power. Power lines are connected to the generator that carry electricity to your home and mine. The water continues past the propeller through the tailrace into the river past the dam. By the way, it is not a good idea to be playing in the water right below a dam when water is released!

This diagram of a hydroelectric generator is courtesy of U.S. Army Corps of Engineers.

As to how this generator works, the Corps of Engineers explains it this way:

"A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydroelectric generator converts this mechanical energy into electricity. The operation of a generator is based on the principles discovered by Faraday. He found that when a magnet is moved past a conductor, it causes electricity to flow. In a large generator, electromagnets are made by circulating direct current through loops of wire wound around stacks of magnetic steel laminations. These are called field poles, and are mounted on the perimeter of the rotor. The rotor is attached to the turbine shaft, and rotates at a fixed speed. When the rotor turns, it causes the field poles (the electromagnets) to move past the conductors mounted in the stator. This, in turn, causes electricity to flow and a voltage to develop at the generator output terminals."

Advantages

1. Once a dam is constructed, electricity can be produced at a constant rate.
2. If electricity is not needed, the sluice gates can be shut, stopping electricity generation. The water can be saved for use another time when electricity demand is high.
3. Dams are designed to last many decades and so can contribute to the generation of electricity for many years / decades.
4. The lake that forms behind the dam can be used for water sports and leisure / pleasure activities. Often large dams become tourist attractions in their own right.
5. The lake's water can be used for irrigation purposes.
6. The buildup of water in the lake means that energy can be stored until needed, when the water is released to produce electricity.
7. When in use, electricity produced by dam systems do not produce greenhouse gases. They do not pollute the atmosphere.

Disadvantages

1. Dams are extremely expensive to build and must be built to a very high standard.
2. The high cost of dam construction means that they must operate for many decades to become profitable.
3. The flooding of large areas of land means that the natural environment is destroyed.
4. People living in villages and towns that are in the valley to be flooded, must move out. This means that they lose their farms and businesses. In some countries, people are forcibly removed so that hydro-power schemes can go ahead.

5. The building of large dams can cause serious geological damage. For example, the building of the Hoover Dam in the USA triggered a number of earth quakes and has depressed the earth's surface at its location.
6. Although modern planning and design of dams is good, in the past old dams have been known to be breached (the dam gives under the weight of water in the lake). This has led to deaths and flooding.
7. Dams built blocking the progress of a river in one country usually means that the water supply from the same river in the following country is out of their control. This can lead to serious problems between neighboring countries.
8. Building a large dam alters the natural water table level. For example, the building of the Aswan Dam in Egypt has altered the level of the water table. This is slowly leading to damage of many of its ancient monuments as salts and destructive minerals are deposited in the stone work from 'rising damp' caused by the changing water table level.

Pumped Storage Plant

Demand for electricity is not "flat" and constant. Demand goes up and down during the day, and overnight there is less need for electricity in homes, businesses, and other facilities. For example, here in Atlanta, Georgia at 5:00 PM on a hot August weekend day, you can bet there is a huge demand for electricity to run millions of air conditioners! But, 12 hours later at 5:00 AM not so much. Hydroelectric plants are more efficient at providing for peak power demands during short periods than are fossil-fuel and nuclear power plants, and one way of doing that is by using "pumped storage", which reuses the same water more than once.

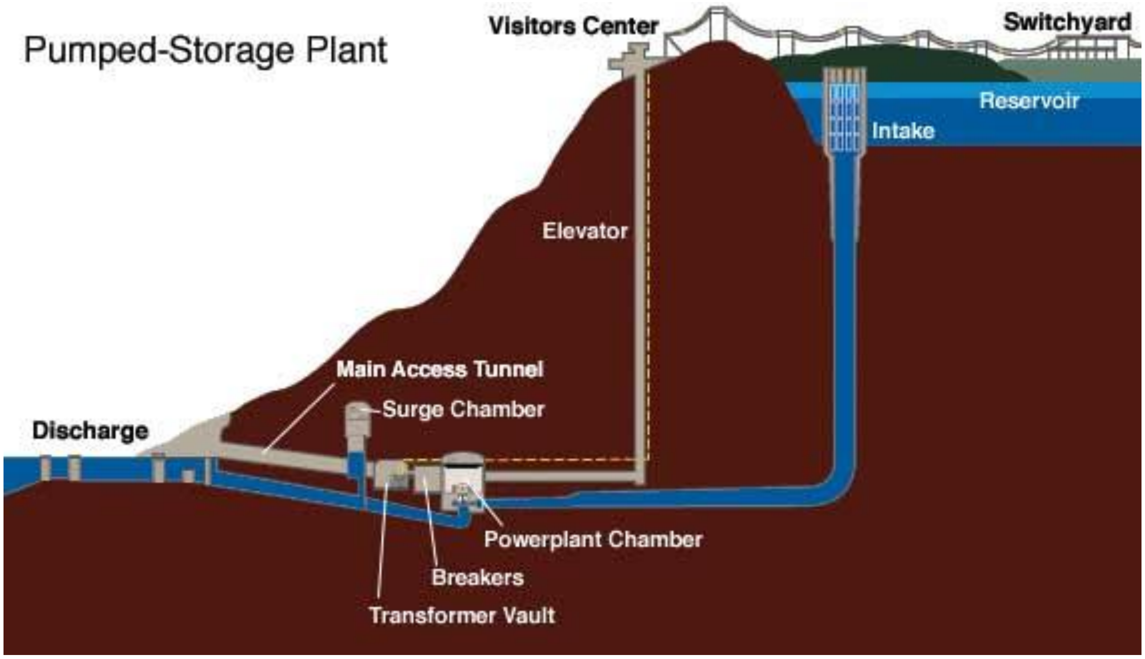

Figure 6: Pumped Storage Plant Reprinted from (Wikipedia, 2015)

Pumped storage is a method of keeping water in reserve for peak period power demands by pumping water that has already flowed through the turbines back up a storage pool above the power plant at a time when customer demand for energy is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is placed on the system.

The reservoir acts much like a battery, storing power in the form of water when demands are low and producing maximum power during daily and seasonal peak periods. An advantage of pumped storage is that hydroelectric generating units are able to start up quickly and make rapid adjustments in output. They operate efficiently when used for one hour or several hours. Because pumped storage reservoirs are relatively small, construction costs are generally low compared with conventional hydropower facilities.

Advantages

1. The complementary nature of the pumped storage plant (Electrical Engineering Tutorials, 2015) to the thermal plant and the possibilities of using storage sites which would not be economical for hydro-power alone, have made pumped storage schemes attractive to power utilities.

2. By adopting pump-storage plant in conjunction with the thermal power plant reduces the capacity of the thermal power plant (which is used as base load plant) and allowed the thermal power plant to operate at almost 100% load factor. It also reduces the start and stop time of the thermal power plant. This method is more economical than conventional plants particularly when an incremental cost of hydroelectric plant is comparatively low and cost of fuel in thermal plant is high.
3. Pumped storage plants are unique among all the hydroelectric power plants as no flowing water supply is required. Once the head or trail pond is filled, then only inflow required is to compensate for the evaporation and separate losses
4. Pumped storage plant has one more notable advantage over conventional hydro-electric installations. In the latter type, when the reservoir level goes down too low, the power generation is interrupted. Whereas in pumped storage plants have advantage of producing electrical power by off-load peak pumping water to the reservoir.
5. The cost of electricity per unit during high demand (peak load demand) is much more costly than that of during off-peak demands. Thus pumped storage plants have the advantages of generating electricity at lower cost compared to other peak load plants (gas and diesel power plants). Water is pumped back to the reservoir during off-peak loads (eg: during night times). Therefore the cost required to pump back is cheaper.
6. By seasonal storage through pumping, the stream flow in other rivers could be used which could otherwise run to waste. This the major advantage of pumped storage power plant.
7. Pumped storage plant capacity is not limited by the river flow and seasonal variations in the flow. This is the advantage of pumped storage plants which can be operated all over the year in all seasons.
8. In a combination of thermal power plant or nuclear power plant as base load plants and pumped storage plants as peak load plants which are constructed to the closer proximity, pumped storage plant can act as reservoir for cooling the thermal units. In addition to this, the proximity of these plants not only valuable because of reduction in the cost of cooling towers for steam power plant as pumped storage plants acts as reservoir, but also it transfer the power to the pumped storage plants during off-peak conditions.The short transmission lines required will keep the losses to a minimum.

9. As with conventional hydroelectric units, pumped storage plants have the advantage of much lower forced-outage rate than the steam generating units. The average plant availability will be of the order of about 95%
10. The reserves of thermal power plants consume appreciable amount of energy for keeping the boiler warm. Whereas the pumped storage plants does not require any additional energy to keep the plant in ready for service. Because of the availability for these plants to pick up the loads instantly, pumped storage plants are used emergency reserve stations or peak load stations in the electrical grid system. For shifting from no load to full load, a thermal station needs nearly 30 to 60 minutes whereas the hydroelectric stations require 20 to 60 seconds for operation. Therefore machines of the pumped storage plants are used for regulating purposes. This is the advantage of pumped storage plant.

Disadvantage

- These plants suffers from economic disadvantage as they require a dual conversion of energy is required.

Power Station

Figure 3 illustrates the design of a power station that contains PV generation, wind power

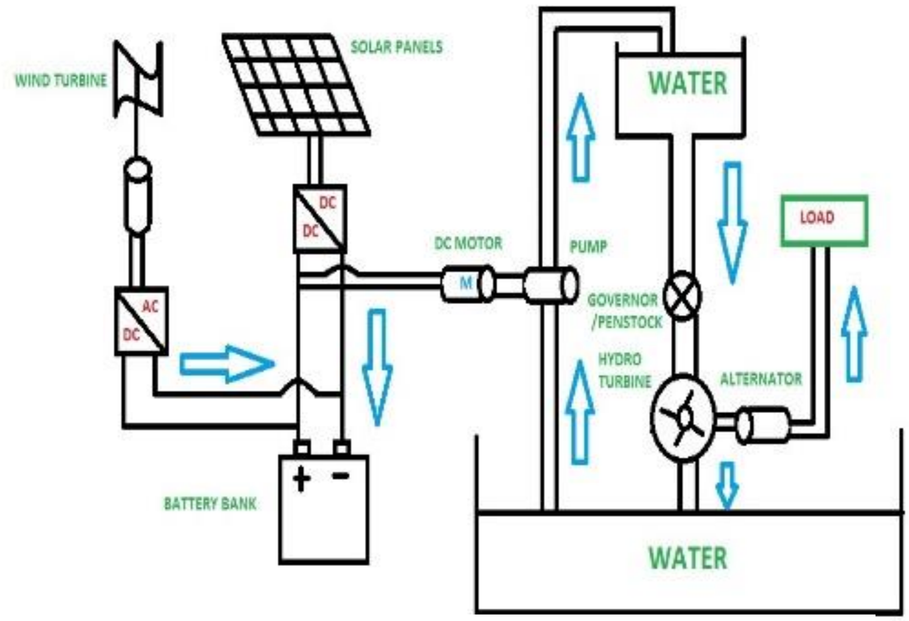

Figure 7: Power Station

generation, pumping and hydropower and other subsystems. According to the solar energy distribution characteristics of site area, in the area both light radiation and radiation intensity is larger during the day, it is except morning and night, the periods of light during the day are more evenly distributed, daytime distribution regularity is similar. Then from PV generation material's photoelectric effect analysis, currently, effective power generation time bears a closer relationship with the sensitivity of optical materials and no significant relationship with capacity. Therefore, it could find the corresponding starting and ending point for power generation according to different light intensity distribution during the day approximate, the period between the two points is the time of photovoltaic materials can be sensitive to the light, but also is the effective work time of photocell in the daytime. The effective period of wind power generation is also effected by the local natural conditions, specific embodied in each period's wind size and continued stability during the daytime, could find the corresponding starting and ending point for power generation according to similar approaches, then determine the effective working days of wind turbine generator. Furthermore pumping systems are affected by the impact of water source and available water supply. Water power of this system can constitute a self-circulation system through pumping unit, external water mainly used as supplement water source; the system demand for water is lower.

Working

From figure 3 we can see that both the renewable energy sources wind turbine and solar panel is connected to a battery bank where the number of batteries are inter connected to store the power. The output of the wind turbine is AC voltage whereas the battery stores only DC voltage so; the output of the wind turbine is connected to a rectifier that converts AC voltage to DC voltage. Thirty solar panels are connected in series to each other to the battery through the DC - DC converter. The power from both solar and wind systems is used to drive a DC motor connected a pump to take water from the reservoir on the ground to the reservoir on the building which is 15m high. Then the water from the upper reservoir is exerted to the turbine by controlling the force using penstock. The mechanical energy from turbine is converted into electrical energy through an alternator and then supplied to the load through an inverter that converts DC to AC.

The water from the turbine is again collected to the tank and then pumped up to the reservoir. From the upper reservoir the water is again exerted on to the turbine with force and this continues until the power station comes to shut down.

If Solar and Wind energy sources run out of energy?

If my energy sources i.e. solar and wind run out of energy, my design has an alternative to come over that criteria for some duration of time. Usually in my design I am using a 3kW motor to pump the water from bottom reservoir to the reservoir on the top and my battery bank can store nearly 7.6kWh, so I can supply some of its power to the motor and I can run the Hydro system by exerting the water on to turbine with some force by using the penstock so that I can generate nearly 5kWh which is half the residential load. Customer can run half of his appliances by using this power. Let us take a worst case scenario what if my Hydro system has also failed, again I had my battery bank. The energy stored in the battery bank is converted to AC and can be used for nearly 5 hours and can run 75% of the appliances. But this design is only for the areas where sunlight and wind are continuously supplying their energy for the whole year.

Cost Analysis

Data Collection

Solar Radiation

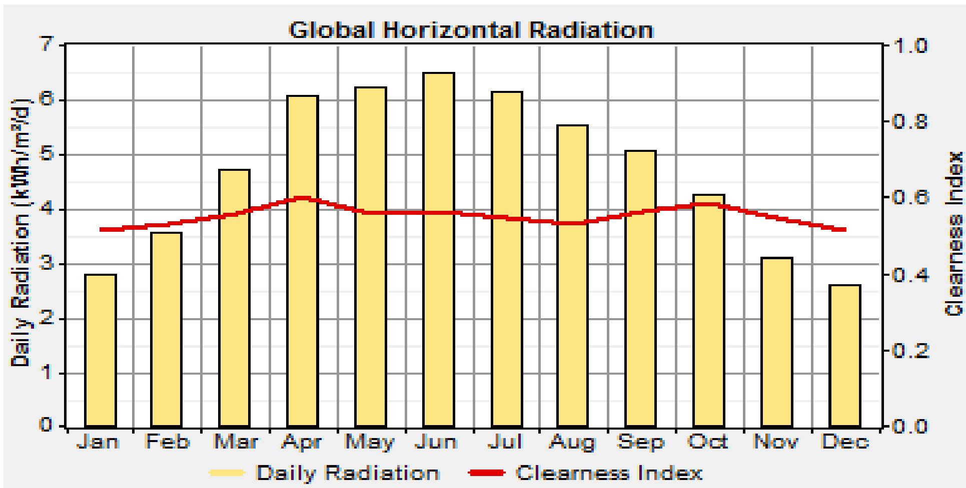

Figure 8: The annual solar radiation and the clearness index

Solar radiation is a reliable source of energy that is received in the form of relatively diffuse energy. Its daily cycle varies and may be influenced greatly by meteorological conditions such as cloud, haze, and fog. Being radiant energy, solar energy cannot be stored directly. Global solar radiation data are readily available and reliable for all locations (Homer Energy, 2012). The solar resource was used for the energy system is in the area of Marietta-United States of America with geographical coordinates defined as: latitude N 33^{o}, longitude W 84^{o}, and altitude 1700m above sea level. The solar radiation data for this region were obtained from the National Aeronautics and Space Administrative (NASA) surface meteorology and solar energy website (Stackhouse, 2014). The annual average of solar irradiation is estimated 4.74 kWh/m^2/day. The solar radiation data inputs as used in HOMER software, on the right axis of which is the clearness index of the solar irradiation is depicted in Figure. The clearness index is automatically generated by HOMER when the daily radiation data are entered (K. Y. Lau, 2010).

Wind Speed

Since the energy from the solar panels is not sufficient to provide the average daily energy demand, wind turbine can be used to provide the remaining power needed (M. Eroglu, 2011). Based on the wind speed data obtained from an anemometer tower (that installed at Weather Channel station, Marietta), the average monthly wind speed variations measured at 10, 20, and

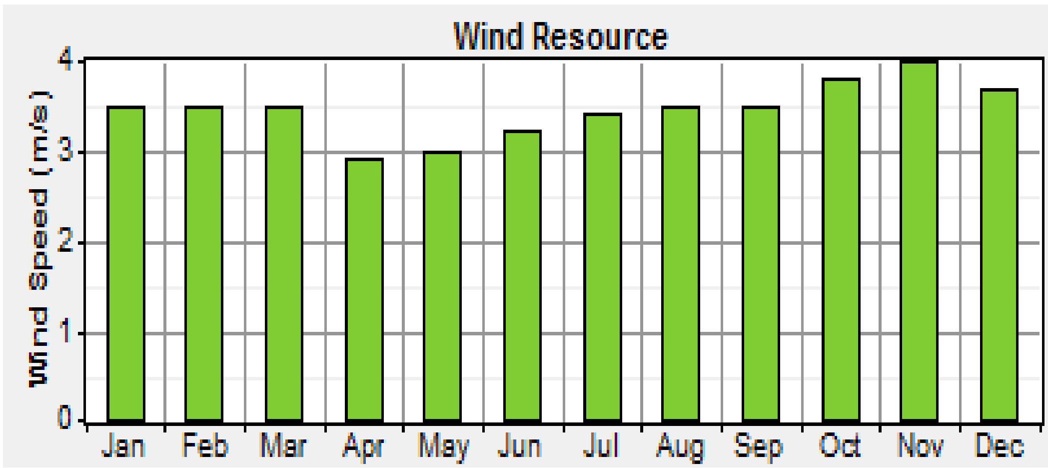

Figure 9: The Monthly Wind Speed Data

40m above the surface of the earth. The data measured at 20m above the surface of the earth are depicted in Figure. Figure shows that the wind speed ranges from 2.9 m/s to 4.0 m/s.

Electrical load demand

A typical sample of the daily load profile for the residential purpose is shown in Figure 6. From the load profile, it can be seen that the maximum demand occurs during a daytime from 6 pm to 6 am as this is the during night times. The scaled annual average energy demand of the studied building is as simulated by HOMER software.

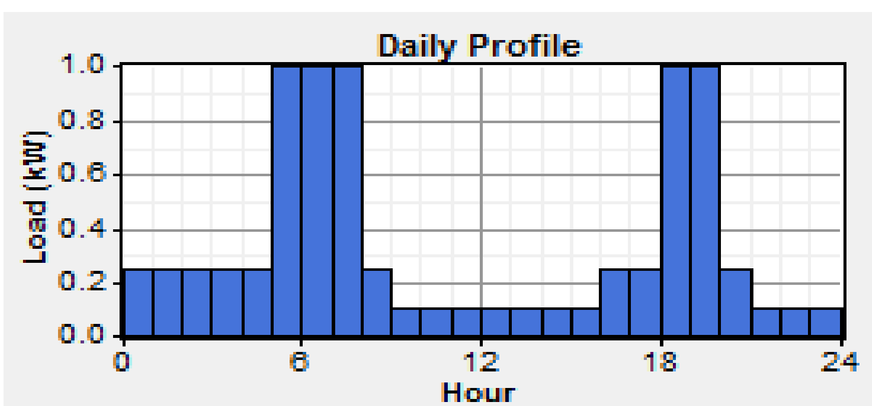

Figure 10: Daily Load profile for the residential site

Specifications of the system

Renewable energy systems are best suited to reduce dependence on fossil fuel using available wind speed and solar radiations (R. Belfkira, 2011). A configuration of a renewable energy system is shown in Figure 5. It consists of solar modules coupled to wind turbine, converter, hydro turbine and battery bank.

In this study, all calculations, simulation, and optimization such as hourly operation of each system, and technical and economic performance parameters have been done by HOMER tools. In addition, we will present the results of techno-economic analysis of integration between solar panels, wind turbine, inverter, hydro turbine and batteries.

Solar/ PV system

Solar energy is one type of the renewable energy resources, which can be converted easily and directly to the electrical energy by PV converters. In this paper, to fulfill the basic load demand, the nominal power rating for the PV modules was set at 10kW. The PV modules consist of solar panels, MA36/45 modules configured into independent sub arrays. Each sub array consists of 16 modules. The PV module is a polycrystalline silicon type with maximum output of 10 kW. In this project, the initial cost of a 10kW solar PV panel is 6386 US$ with a replacement cost of 4000 US$. Derating factor is a scaling factor applied to the PV array power output to compensate the reduction in PV module efficiency (Homer Energy, 2012). In this simulation, the derating factor is assumed to be 80%. The ground reflectance of solar radiation is 20%, and operational and maintenance (O&M) cost for PV array is 200 US$, and the lifetime is assumed to be 25 yr.

Wind Turbine

Since the energy from the PV panels is not sufficient to provide the average daily energy demand, a wind turbine cell can be used to provide the remaining power needed. [10] The fundamental equation governing the mechanical power capture of wind turbine rotor blades which drives the electric generator is given by (P. Wang and R. Billinton, 2001) (Wind turbines, 2013)

$$P_m = \frac{1}{2} C_p . \rho . A . V_{wind}^3 \tag{1}$$

Where q is the air density (kg/m^3), A is the rotor sweep area, V is the wind velocity (m/s), and C_p represent the power coefficient of the wind turbine. Thus, if the air density, swept area, and wind speed are assumed constant, the output power of the wind turbine will be a function of the power coefficient. The wind turbine is normally characterized by its C_p–TSR characteristic, where the TSR is the tip speed ratio and is given b

$$TSR = \frac{\omega.R}{V} \quad (2)$$

In Eq. (2), R and ω are the turbine radius and the mechanical angular speed, respectively and

V is the wind speed. To keep power coefficients at its maximum value, operating TSRs must be held at its optimal value by controlling rotor speeds according to reference rotor speeds at incoming wind speeds using a maximum power point tracking (MPPT) controller.

In this simulation, the Generic 3kW (DC) type wind turbine was chosen. Table I shows the costs of the wind turbine. For economic assessment, the operating and maintenance cost is assumed to be 4%.

The battery bank

Energy supply systems based on renewable energy sources require energy storage because of their fluctuation and the insufficient certainty of supply. One of the ways for energy storage is the use of the battery bank. Due to the stochastic nature of the electrical output of PV system and wind turbine, energy storage is needed to supply the load “on demand” by storing energy during periods of high bright sun. When the total outputs of the PV array and wind turbine are more than the energy demand, the battery bank is charged. HOMER tools assume that the properties of the battery remain constant throughout its lifetime and are not affected by external factors such as temperature.

In order to produce higher energy capacity, batteries are connected in series, which form battery string. The estimated price of each battery is 200 US$ with a replacement cost of 200 US$. This battery is characterized by their versatility of application and zero-maintenance design. The life expectancy of battery is 10 yr. The 4V battery bank originally consisted of 7.6 kWh of storage.

Converter

A converter is required for a system in which DC components serve as an AC load or vice versa. It can operate as a rectifier which converts AC to DC, an inverter which converts DC to AC, or both. The estimated capital cost of an inverter is 600 US$ and replacement cost of 600 US$. A lifetime of 20 years was assumed in which the both inverter and rectifier efficiencies were assumed to be 90%, for all sizes considered.32 HOMER was used to simulate each system with power switched between the inverter and the generator.

Table 1: Cost and specifications of the components

S.no	**Components**	**Nominal Power (kW)**	**Capital Cost (US$)**	**Replacement Cost (US$)**	**Operating and Maintenance Cost (US$)**	**Life Time (yrs)**
1	Solar Panels	10	6386	4000	200	25
2	Wind Turbine	3	9000	9000	360	25
3	Battery Bank	7.9	800	800	100	12
4	Converter	14	600	600	10	20
5	Hydro Turbine	23.5	2000	2000	150	25

Results and Discussions

Simulation of Power Station by HOMER tools

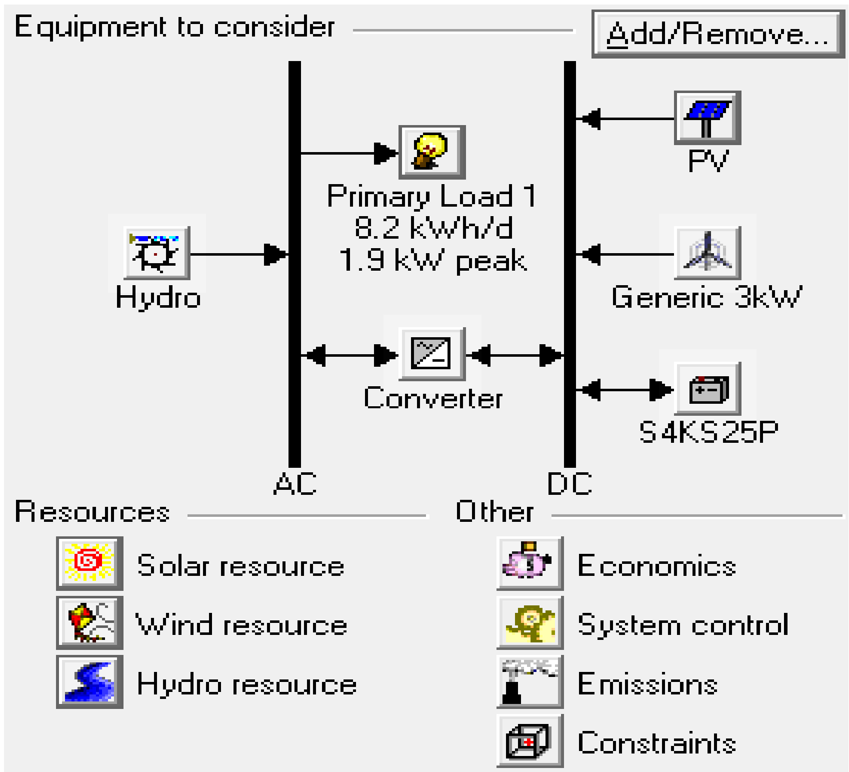

Figure11: Schematic of Power station

In this study, the selection and sizing/dimensioning of components of the hybrid energy system have been done using NREL's HOMER software. HOMER is general-purpose hybrid system design software that facilitates design of electric power systems for stand-alone applications. Input information to be provided to HOMER includes: electrical loads (1 yr of load data), renewable resources (such as 1 yr of solar radiation data), component technical details/costs, constraints, controls, type of dispatch strategy, etc. HOMER is a simplified optimization model/code, which performs hundreds or thousands of hourly simulations over and over (to ensure best possible matching between supply and demand) to design the optimum system. It uses life-cycle cost to rank order these systems. It offers a powerful user interface and accurate sizing with detailed analysis of the system. The software performs automatic sensitivity analyses explaining the sensitivity of the hybrid system design to key parameters, such as the resource availability or component costs. The simulation was done with a project's lifetime of 25 yr. Moreover, an annual interest rate of 8% was used in the economic calculations. The schematic diagram of the stand-alone hybrid energy system as designed in HOMER simulation software is shown in Figure 7. This system has an average AC load of 8.2kWh/days, with the peak load of 1.9kW. HOMER allows input of the operating reserve in the system. The result of here required the operating reserve to be 10% of the hourly load, plus 60% of PV array, and 40% wind turbine power output.

Power Station Optimization results

Hourly solar radiation and wind speed measurements for a period of 1 yr were imported into HOMER tools to calculate monthly average values of clearness index and daily radiation. The annual average global radiation is 4.72 kWh/m2/day with an annual average clearness index of 0.555, and the annual average wind is 3.46 m/s. The results are displayed, an overall form in which the top-ranked system configurations are listed according to their NPC for possible system type. Table 2 shows a list of the possible combinations of system components in the overall form. The table has been generated based on inputs selected. The system was simulated to evaluate its operational characteristics, annual electrical energy production, annual electrical loads served, excess electricity, RE fraction, capacity shortage, unmet load, etc. some environmental impact parameters of the system. A load-following control strategy was followed in the simulation. Under this strategy, whenever a power generator is needed it produces only enough power to meet the demand.

Table 2: Electric Energy production

PV (kW)	G3	Hydro (kW)	S4KS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
10	1	23.5	4	14	CC	$ 18,786	860	$ 29,775	0.779	1.00

Load following strategy tends to be optimal in systems with a surplus of renewable energy. The results of the simulation showed that this system had a total annual electrical energy production of 15825kWh, which the total energy produced from a PV array is higher than the energy generated from wind turbine. All results related to the electric energy production, and electric energy consumption is summarized in Table 2. According to the results of the optimization process, the optimal energy system (see Figure 8) comprises 10kW PV modules, one wind turbines (3kW each), 14kW converter and four batteries. The cost of energy (COE) of the studied systems is 0.783 US$/kWh, whereas the initial capital required and NPC are 32831 US$, respectively. This could be a good choice for implementation as the contribution made by renewable resources is quite significant. Figure 8 shows average monthly electrical production of this system. The assessed values about total annualized cost and net present costs for each component of the energy system are presented in Table 1.

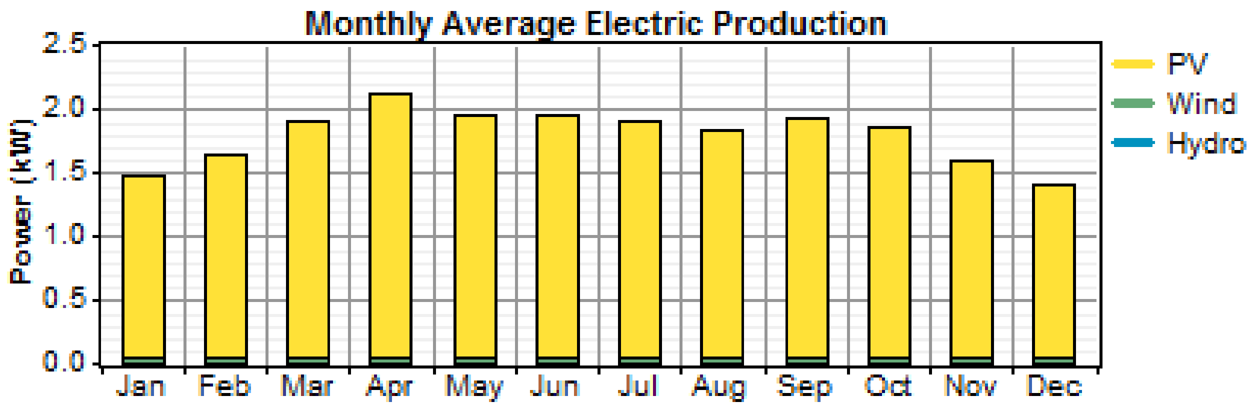

Figure 12: Monthly Average Electric Production

Conclusion

The net financial benefit for altering the solar and wind power system into a solar-wind pump-storage power system is shown by cost analysis. No modifications were made to the type and number of solar panels or to the wind turbines used by “Nichita, Livinti, and Enache (“Nichita, 2014)” research team. It is thus concluded that a significant improvement of the existing system was achieved, reducing the number of storage battery units and some of the power converters by using HOMER tools. It is necessary to emphasize that pump-storage power systems are best suited for locations/areas where “natural” water head is offered by the surrounding topography, whereas flat land topography would require expensive structural accommodations, resulting in a far more expensive design, as compared to the existing solar and wind power system (with battery storage capability).

Future upgrades/ideas

- Making money by connecting the system to grid.
- Power generation in extreme climatic conditions.
- Perpetual Machine that runs continuously through pumping system.

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